



# PURIFIED PHOSPHO RIC ACID

$\text{H}_3\text{PO}_4$   
TECHNICAL INFORMATION BULLETIN

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# INTRODUCTION

## General Description

Orthophosphoric acid ( $H_3PO_4$ ), usually referred to as phosphoric acid, is a clear, water-white liquid which is derived from phosphate rock.

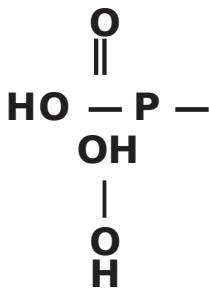
Phosphoric acid is a triprotic acid which means that, in an aqueous solution, it will dissociate to produce three hydrogen ions. Phosphoric acid is a stronger acid than the organic acids, such as acetic, citric and lactic; however it is not as strong as other mineral acids, such as nitric, sulfuric and hydrochloric.

Phosphoric acid is a useful synthesis catalyst since it does not react violently with many organic compounds and exhibits catalytic and dehydrating properties. It will react readily with bases to produce alkali phosphates and will become fairly reactive with metals and metal oxides at elevated temperatures.

These properties give phosphoric acid a wide range of industrial applications from metal finishing to food additives.

## Structure

### re



CAS Registry No: 7664-38-2

The molecular structure of orthophosphoric acid represented above in two dimensions, consists of four groups at the corners of a tetrahedron with the phosphorus atom at the center. In aqueous solutions, the phosphate ions are considered to be interconnected by hydrogen bonds. As dilution increases, hydrogen bonding between phosphate ions decreases and is replaced by hydrogen bonding to water.

# Specifications

## Technical Grades

	75%	80%	85%
Appearance		Water-white liquid, colorless, odorless.	
Specific Gravity (25°C/15.5°C)	1.574	1.629	1.686
Phosphoric Acid (%H <sub>3</sub> PO <sub>4</sub> )	75.0 - 75.5	80.0 - 80.5	85.0 - 85.5

## Food Grade Specifications

Componen t	75% Food		80% Food		85% Food	
		Chemical Codex		Chemical Codex		Chemical Codex
H <sub>3</sub> PO <sub>4</sub>	%	75.0 - 75.5		80.0 - 80.5		85.0 - 85.5
F	ppm w	10		10		10
As	ppm w	3		3		3
Heavy Metals	ppm w	5		5		5
Cd	ppm w	3		3		3
Pb	ppm w	3		3		3

## Physical Properties

	Standard Concentration		
	75%	80%	85%
P <sub>2</sub> O <sub>5</sub> (%)	54.6	58.1	61.7
Specific Gravity (25°C/15.5°C)	1.574	1.629	1.686
Pounds per U.S. Gallon	13.1	13.6	14.1
Melting Point*, Approx.	0°F(-18°C)	41°F(5°C)	70°F(21°C)
Specific Heat (cal/gm-°C)	0.542	0.518	0.493
Viscosity (25°C) cp	21.5	29.0	43.5

\* Purified phosphoric acid's melting point is the same as its freezing point.

## Availability

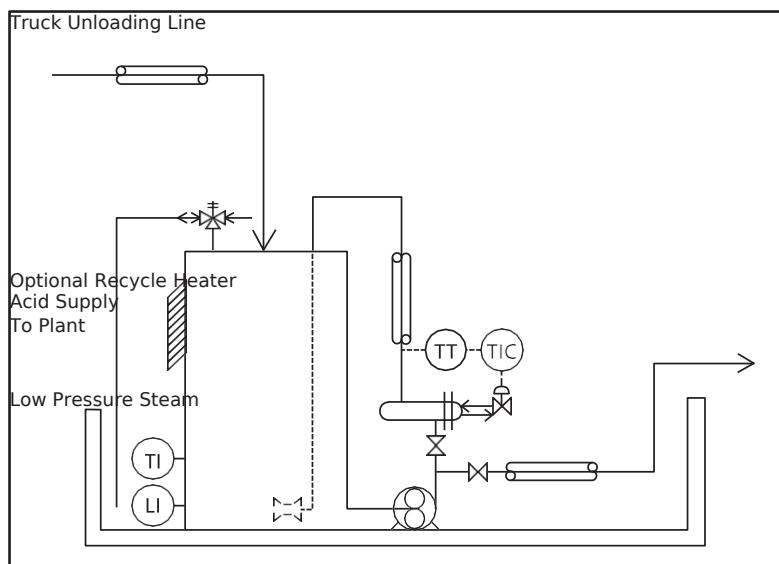
PCS phosphoric acid is available in three standard concentrations, 75%, 80%, and 85% meeting the aforementioned specifications. Bulk shipments can be made in tank cars and tank trucks. Phosphoric acid in polyethylene drums is also available from your PCS distributor.



# BULK STORAGE AND HANDLING

## Storage Considerations

The primary considerations in the design of a bulk storage and handling system for phosphoric acid are its corrosive properties and freezing point. The freezing point of phosphoric acid varies greatly with acid concentration. It is this consideration that determines the tank location and need for an external heating source. Phosphoric acid is subject to supercooling well below the freezing point if there is no seeding or agitation. For this reason 75% acid can be stored outside with little danger of freezing. The 80% and 85% acid grades may require some form of external heat to keep them above their freezing points, depending upon the location of the system. Temperature can be controlled using a recirculation loop with an external heat exchanger. Low temperature steam, electricity or hot water are recommended as heat sources. A schematic of a typical phosphoric acid storage system is shown in Figure 1.



**FIGURE 1: Schematic of Typical Phosphoric Acid Storage System**

## Construction Materials

### Storage Tank

Recommended materials for storing phosphoric acid are:

- **Stainless Steel**

Type 316L Stainless Steel is used successfully for storing all grades of phosphoric acid. It is especially desirable for food grade acids. To avoid welding difficulties, extra low carbon (ELC) stainless steel should be specified. MIG welding should also be specified since the quality of the welds is superior. The corrosion rate for 316L in the temperature range from 77° to 120°F is low. A caution to be observed when considering stainless steel tanks is the detrimental effect of minor amounts of halide impurity (15 - 30 ppm Cl) in the acid. This amount of chloride will increase the aggressiveness of acid to stainless steel enough to increase the Fe, Ni and Cr content in the acid, and impart color to the product.

This is especially true where small amounts of acid remain in contact with a relatively large surface as in pipelines or in the bottom of a tank. PCS phosphoric acid contains less than 5 ppm of chlorides and will cause no difficulty. However, if the acid is diluted with chlorinated water, the chloride concentration can reach a level which results in corrosion of the stainless steel.

**• Rubber-Lined Carbon Steel**

Rubber-lined steel tanks offer good corrosion resistance and are less expensive than stainless steel. Pure natural gum white rubber and chlorobutyl rubber are recommended, though resistance varies with manufacturers. New rubber linings often impart some color to phosphoric acid but this usually drops to an undetectable level after several storage cycles.

Some rubbers have a tendency to become detached from the steel tank. This is usually due to failure of the bonding cement used. It should be noted that elevated temperatures have a deteriorating effect on the rubber lining, with each lining having its own "critical" temperature.

B.F. Goodrich produces ACID SEAL PW code 2004 which is a soft, white natural rubber and is suitable for installation on site. Goodrich SANIPRENE code 1005 is a hard rubber for smaller tanks which are autoclave cured. ARCO (Schoolcraft, MI) also produces comparable materials: #8310 for field installation and #874 for the smaller applications. Blair Rubber Company produces VE 524WC FDA, which is a white chlorobutyl rubber.

**• Fiberglass Reinforced Polyester (FRP)**

Filament-wound fiberglass with polyester resins is also used successfully. The performance of the fiberglass tank surpasses that of the rubber-lined tank and is nearly equal to that of stainless steel. The most pronounced advantage of fiberglass is one of initial cost. Fiberglass tanks are less expensive than rubber-lined tanks and can cost one-third as much as stainless steel. Bisphenol-A-Fumarate is recommended as a polyester resin. Do not use steam coils in FRP, rather use hot water or electrical heaters.

The following materials are not recommended:

**• Glass-Lined Steel**

Glass lined tanks have superior corrosion resistance. However, the cost is excessive for this application.

**• 302, 304 and 316 Stainless Steel**

Type 302, 304 and 316 stainless steel are less expensive than 316L. However, the corrosion rates with phosphoric acid are greater. They impart a green color to the acid due to the increase in the heavy metals concentration. They are also more sensitive to chloride contamination than type 316L. None are considered suitable materials for storing or handling phosphoric acid.

**• Carbon Steel**

Although carbon steel is much less expensive than stainless steel, it corrodes rapidly when in contact with phosphoric acid. It should never be used in any aspect of the transfer, storage or handling of phosphoric acid.

The foundation around bulk storage tanks should be diked. It is recommended that the dike be designed to hold 110 percent of the volume of the storage tank or of the largest tank in the tank farm. The floor of the dike should drain towards a sump to allow any water accumulating in the diked area to be removed using a pump. The sump and diked areas should be kept drained. The dike walls and floor should be protected with an acid-resistant coating. STONHARD® Company, Forté Composites Inc. (Corguard 9000), and AMERON PROTECTIVE COATINGS produce acceptable acid-resistant coatings.

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## **Pumps**

Phosphoric acid pumps should have all wetted parts constructed of 316L stainless steel. Centrifugal pumps capable of meeting the pumping capacity and dynamic head are sufficient. Mechanical seals are recommended over packing due to their longer life span. Centrifugal pumps such as the totally enclosed, sealless Crane Chempump can also be used, but are more expensive and not usually justified.

## **Piping**

In general, any material suitable for storing phosphoric acid will be acceptable as a piping material with 316L being preferred.

When stainless steel piping is used, best results have been obtained using flanged and welded type 316L pipe, fittings and valves. Schedule 40 pipe should be used with type 316L insert-type flanges. These flanges have 316L welding and sealing surfaces with carbon steel back-up flanges. Welding should be done by competent personnel according to methods approved by the stainless steel manufacturer.

All 316L or Alloy 20 flanged valves with outside screw and yoke are recommended. TEFILON gaskets are recommended. Screwed stainless steel pipe, fittings, and valves are used but are not recommended because it is difficult to obtain tight joints, particularly when the piping is to be dismantled and reassembled. The flanged and welded piping system is preferred.

# HEALTH AND SAFETY INFORMATION

Phosphoric acid is considered to be a stable chemical not subject to thermal or photochemical decomposition. Hazardous polymerization will not occur. Hazardous decomposition products are the phosphorus oxides which are evolved at approximately 3000° to 3200°F.

Phosphoric acid will react with some metals such as aluminum and zinc liberating hydrogen; however it does not react as rapidly or violently as some of the more active acids. Nevertheless, caution should be exercised since the by-product hydrogen is very flammable.

Material Safety Data Bulletins should be consulted prior to use of the products and are available by contacting PCS Sales Customer Service Department.

North  
America 1-  
800-654-  
4514

## **Fire, Explosion and Health Hazard Data**

Phosphoric acid does not burn and exhibits no unusual fire explosion hazards. The Threshold Limit Value Time Weighted Average (TLV TWA) is 1.00 milligram per cubic meter of air and respiratory irritation from excessive breathing of mists of vapors will occur. There can also be moderate eye irritation and slight skin irritation.

## **Toxicological Information**

Phosphoric acid exhibits slight oral toxicity in rats with an LD50 of 1530 mg/kg of body weight. Dermal toxicity is considered to be slight based on testing of similar products and/or the components. Severe skin irritations or burns may occur. Phosphoric acid will cause eye burns. Detailed toxicological data is available from PCS Environmental Services Department, Northbrook, IL.

## **Personal Protective Equipment**

Properly fitted chemical goggles and protective clothing should be worn. Impervious gloves and aprons are recommended. No special respiratory protection is required under ordinary conditions of use provided that adequate ventilation is maintained. When vapor or mist concentrations exceed applicable standards, approved respiratory protective equipment must be used.

# EMERGENCY INFORMATION

## Spill Containment

Phosphoric acid is not volatile or flammable. The primary concern in the event of a spill is to contain the material to prevent contamination of sewers or waterways. If the leak or spill is not contained in a diked area, the spilled material should first be contained using dry sand banked around the spill to limit the affected area. Then sprinkle hydrated lime or soda ash on the spill area. Finally, shovel the material into an approved waste disposal container for treatment or disposal in an approved chemical disposal area.

## Emergency First Aid Procedures

### Eye Contact

Flush eyes thoroughly with water for 15 minutes. Get immediate medical assistance. If medical assistance is not immediately available, flush an additional 15 minutes.

### Skin Contact

Wash contaminated skin with mild soap and water. If clothing is contaminated, remove clothing immediately and wash exposed area with large quantities of water. Launder contaminated clothing separately before reuse. If contact is widespread, remove clothes and wash skin under a safety shower.

### Inhalation

Remove from further exposure. If breathing has stopped, use mouth-to-mouth resuscitation. Keep affected person warm and get immediate medical attention.

### Ingestion

Do not induce vomiting. Give one to two glasses of water or milk immediately. Get medical assistance immediately. Do not give anything by mouth to an unconscious person.

## Transportation Emergencies

For help with emergencies involving spill, leak, fire or exposure involving transportation equipment, immediately notify the closest Emergency Center:

U.S. CHEMTREC 1-800-424-9300 or 202-483-7616  
Canada CANUTEC 613-996-6666

The information specialist on duty will ask for a brief description of the emergency, the name and location of the caller, the name of the shipper, the product, the shipping point and destination, what happened, the nature of any injuries, weather conditions, proximity of populated area, etc. He will then give the recommendation for controlling the emergency situation until the shipper's specialist can relay help. CHEMTREC will advise PCS of the emergency and one of our specialists will contact the caller.

# APPLICATIONS

## Chemical Production

### Alkali Phosphates

Phosphorus-based builders for the detergent industry is a major application for phosphoric acid. A base such as potassium hydroxide, sodium hydroxide or soda ash (sodium carbonate) is reacted with phosphoric acid and the resulting "wet mix" is dried to form alkali phosphates in the ortho or condensed form. The properties of the resulting alkali phosphate are dependent on the method of drying, the temperature and process time, and the alkali-to-phosphorus molar ratio. Some common phosphate builders are sodium tripolyphosphate, tetrasodium pyrophosphate, tetrapotassium pyrophosphate, potassium tripolyphosphate, and trisodium phosphate.

Phosphoric acid can also be combined with an ammonia base to produce monoammonium phosphate, diammonium phosphate, or ammonium polyphosphate. These compounds are used in fertilizer manufacture and flame proofing.

### Catalysts

Purified Phosphoric acid is used in the production of several catalysts. Vanadium/phosphorus oxide catalysts have been produced<sup>(15)</sup> for use in hydrocarbon oxidation reactions. It is claimed to deliver higher yields with better selectivity in the production of maleic anhydride from C<sub>4</sub> hydrocarbons. Phosphoric acid is also used in the manufacturing of aluminum phosphate catalysts and can be used to extend the life of catalysts by reducing coking.<sup>(16)</sup>

### Specialty Fertilizers

Purified Phosphoric acid is used as the phosphorus source in the production of specialty and foliar fertilizers. Because of its higher purity and lack of solids, purified phosphoric acid is used for spray and house plant fertilizers.

### Fire Retardants

Wood and cellulose materials can be treated to obtain flame, glow and decay resistance. The current formulation<sup>(17)</sup> uses urea, dicyandiamide, formaldehyde and phosphoric acid to form coatings, impregnated substrates, adhesives and resins. The fire retardant formulation is stable and leach resistant, and exhibits a useful shelf life.

## Food and Beverages

### Beverages

Food grade phosphoric acid is used in the beverage industry as an acidulant and flavoring agent. The presence of 0.05% phosphoric acid contributes to the unique taste of cola drinks. Phosphoric acid is also a less expensive additive for beverages than citric, tartaric, acetic and lactic acids.

## **Cheese**

Phosphoric acid is used in the dairy industry as an acidulant to cause curdling in the production of cottage cheese.

## **Egg Products**

Phosphoric acid can be used to minimize the viscosity and browning in the spray drying of egg albumen.

## **Fats and Oils**

Phosphoric acid can be added to fats and oils as an emulsifier and to aid in the control of fatty peroxides. It is also used as a degumming agent during vegetable oil refining.

## **Gelatin**

Phosphoric acid can improve the setting rates and clarity of gelatins.

## **Jams and Jellies**

Small amounts of phosphoric acid can be added to jams and jellies for acidifying, buffering and preservation.

## **Salad Dressings**

Phosphoric acid is used as an acidulant in some salad dressings.

## **Sugar Refining**

In the refining of raw sugar, phosphoric acid is reacted with lime to form a calcium phosphate precipitate which aids in the filtration of particulates.

## **Pet Foods**

Phosphoric acid is used in the production of semi-moist pet food.

## **Metal Treating**

In the metal finishing industry phosphoric acid is utilized to chemically polish, clean and coat a wide range of metals, including aluminum, brass, copper, steel and stainless steel.

## **Aluminum Brightening**

Most of the solutions employed in the metal finishing industry for the chemical polishing of aluminum are based on a mixture of phosphoric acid, nitric acid, and sometimes sulfuric acid. These solutions, commonly referred to as bright dip solutions, chemically remove the microscopic peaks of the aluminum surface to produce a highly specular or mirror-like finish. Chemically polished aluminum can be utilized in a variety of applications including automotive trims, architectural structures, home appliances, aircraft construction, electronic components, window frames, shower doors, cosmetic containers, athletic equipment, office equipment, and many more. PCS's *Phosbright* and *DAB* solutions set the standard for bright dipping of aluminum and they can be custom formulated to include any combination of the following additives: copper metallic brightener, fume suppressant, or etch inhibitor.

Consistent production of a high quality finish requires a thorough understanding of the bright dip bath and its function, as well as careful control of the entire finishing process. PCS maintains a technical staff with laboratory and pilot facilities to assist metal finishing customers with implementing process improvement modifications on existing bright dip/anodizing lines or with designing new lines, and with troubleshooting to determine the cause of various finishing problems. PCS provides analytical services at no charge to customers for determining the different operating parameters of the customer's bright dip baths. PCS also provides, at no charge, sample kits for sending bright dip samples to PCS's lab and reagents to assist in bright dip bath control.

## **Aluminum Cleaning**

In the aluminum industry, it is of vital importance to have a clean surface on the aluminum part prior to implementing any finishing process. The cleaning of aluminum can be accomplished by either an alkaline cleaner alone or an alkaline cleaner followed by an acid cleaner. PCS offers a phosphoric acid-based cleaner referred to as *342 Acid Cleaner*. This cleaner is designed to remove ground-in, caked-on buffering compounds and drawing oils from drawn, stamped, or extruded aluminum parts and leaves the aluminum surface "activated" for subsequent bright dipping or etching processes. It will also remove some heat and watermarks, which are normally carried through conventional alkaline or neutral cleaners. *342 Acid Cleaner* is designed as a second-stage cleaner that follows an alkaline cleaner, but it may be used as a single-stage cleaner where the soil load is light.

## **Boiler Cleaning**

Many boiler cleaning formulations utilize phosphoric acid to remove carbonate scale, oil or grease. The advantage of phosphoric acid is that the boiler surfaces will develop a light phosphate coating which will resist further oxidation. Phosphoric acid is also less corrosive and volatile than other mineral acids.

## **Dairy Equipment Cleaning**

Phosphoric acid is used in the dairy industry as a cleaner and sanitizer. It has the advantage of being non-toxic and very effective at removing "milk stone" from the processing equipment.

## **Electropolishing<sup>(18)</sup>**

Carbon steel, stainless steel, copper, brass and aluminum can be electropolished using a bath of phosphoric-sulfuric-chromic acid in varying concentrations. The metal is made the anode and the bath selectively removes the microscopic metal peaks resulting in increased specularity.

## **Phosphate Coatings**

Metal phosphate coatings are applied to various metal surfaces to reduce corrosion, to improve paint bonding and to aid in forming or break-in processes.

Many phosphatizing solutions have been developed but the most common ones contain free phosphoric acid, a dissolved metal phosphate, an accelerator and a surfactant. The coating is formed when the free phosphoric acid reacts with the metal to produce a metal phosphate which is insoluble and precipitates. The accelerator can be nitrate, chlorate or a nitrite and serves to increase the reaction rate. The surfactant acts as a wetting agent to improve the contact between the metal surface and the solution.

The phosphate coating is bonded tightly to the metal surface and is normally formulated to be porous, which provides an excellent substrate for paint adhesion. In addition, the pores can hold lubricant to improve the forming operations and reduce friction during equipment break-in periods.

## **Refractories and Ceramics**

Phosphoric acid is useful as a bonding agent in many refractories and ceramics. It is also used as a raw material in the production of the improved bonding agents such as monoaluminum phosphate and monomagnesium phosphate solutions. The high purity of PCS acid allows for an extended shelf life of the mixes plus consistently high strength bonds in the final refractory.

Much research has been done on the bonding of high alumina refractories and these compositions display high temperature resistance and high strength. Various additives have been patented to improve specific properties of the refractory compositions.

A refractory with a large amount of chromic oxide has been proposed<sup>(19)</sup> which is claimed to have improved thermal shock resistance and reheat expansion. The addition of tetrasodium pyrophosphate and bentonite<sup>(20)</sup> has been shown to improve workability and storage life of ramming or hand mixes. A refractory containing silicon metal and graphite has been claimed to be resistant to slag and hot metal erosion.<sup>(21)</sup>

## **Miscellaneous**

### **Fuel Cells**

Phosphoric acid is used as an electrolyte in fuel cells which produce electricity from the conversion of hydrogen to water.

### **Activated Carbon Production**

The production of activated carbon involves mixing wood fibers or sawdust with phosphoric acid followed by calcination in a rotary kiln.

### **Waste Treatment**

Phosphoric acid is used as a nutrient for bacteria in activated-sludge waste treatment systems.

### **Lead Fixation**

Phosphoric acid can be used to form non-leachable lead phosphate in land areas where potential lead runoff is a problem.

# BASIC PROPERTIES

## Boiling Points

The boiling point for orthophosphoric acid is shown in Figure 2 which graphs the boiling point at one atmosphere pressure versus the concentration expressed as weight percent phosphoric acid (%  $\text{H}_3\text{PO}_4$ ). Through the concentration range of 0% to 100%, boiling acid will give off very nearly pure water.

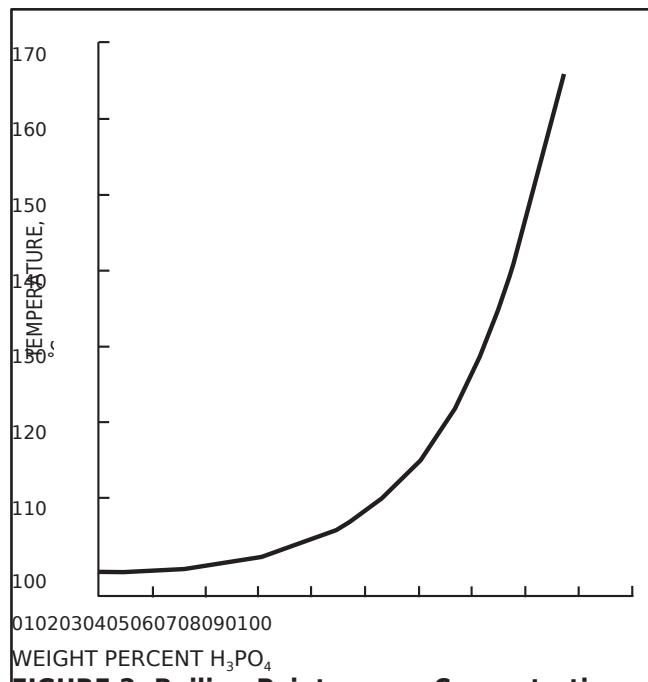


FIGURE 2: Boiling Point versus Concentration

## Freezing Points

Figure 3<sup>(1)</sup> is the phase diagram of the  $\text{H}_3\text{PO}_4$  -  $\text{H}_2\text{O}$  system showing the freezing point curve for phosphoric acid through the range of 0 to 100 weight percent  $\text{H}_3\text{PO}_4$ . Concentrated phosphoric acid tends to supercool before crystallization occurs. The freezing points of standard concentrations are as follows:

### Acid Strength

(% $\text{H}_3\text{PO}_4$ )	80	85
%	%	%
<b>75%</b>		
Freezing Point	40.2° F	70.0° F
0.5°F		
-	4.6° C	21.1° C
17.5° C		

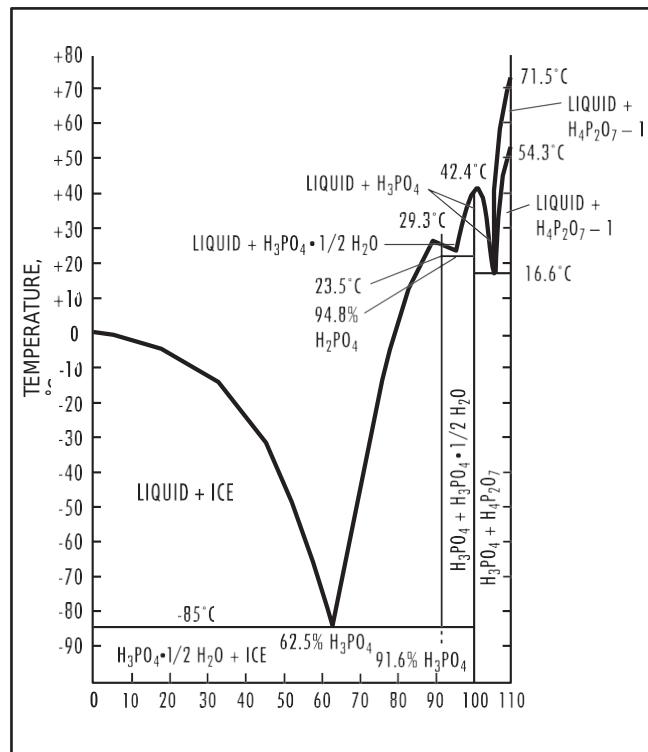


FIGURE 3: Freezing Point versus Concentration

## Conversion Factors

Phosphoric acid concentrations can be expressed in several ways: percent phosphoric acid (%H<sub>3</sub>PO<sub>4</sub>), percent phosphorous pentoxide (%P<sub>2</sub>O<sub>5</sub>), or percent phosphorus (%P). The following chart gives the factors to convert from one of the above concentration units to another.

To Convert		To:		
From:		H <sub>3</sub> PO <sub>4</sub>	P <sub>2</sub> O <sub>5</sub>	P
H <sub>3</sub> PO <sub>4</sub>	X	—	0.724	0.316
P <sub>2</sub> O <sub>5</sub>	X	1.381	—	0.436
P	X	3.164	2.291	—

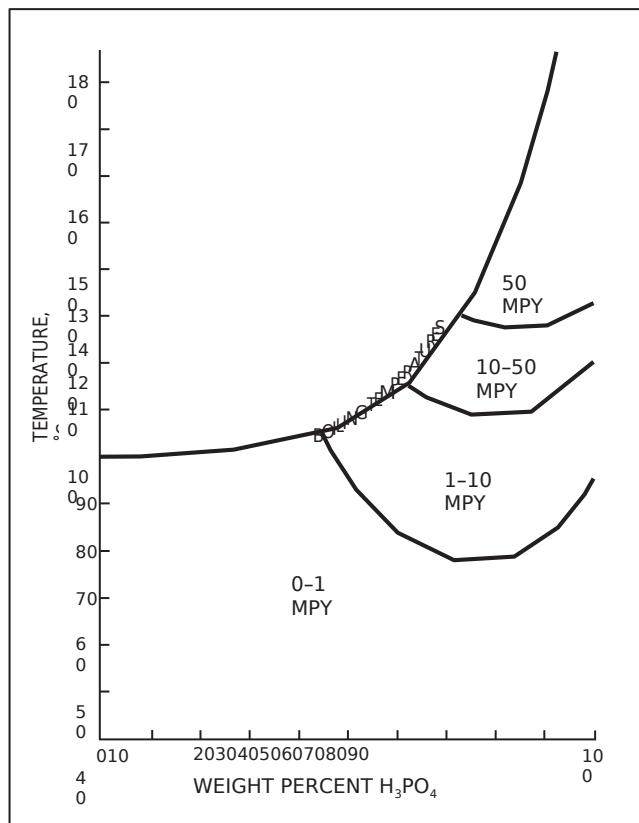
For example, to convert from 75% H<sub>3</sub>PO<sub>4</sub> to % P<sub>2</sub>O<sub>5</sub>: 75% H<sub>3</sub>PO<sub>4</sub> x 0.724 = 54.3% P<sub>2</sub>O<sub>5</sub>

## Corrosion Data

One of the most widely used alloys for phosphoric acid is stainless steel type 316L. Figure 4 (right) is an isocorrosion chart<sup>(2)</sup> for type 316L stainless steel showing the corrosion rate for various concentrations at various temperatures.

Fiberglass reinforced polyester is also a corrosion resistant and cost effective material for phosphoric acid (HF free) but only at ambient temperatures.

In addition, numerous other metallic and non-metallic materials have been tested in phosphoric acid and are listed in Figures 5A and B<sup>(3)</sup> (pg. 14). The corrosion values are only applicable to high purity phosphoric acid. The values will be higher for PCS phosphoric acids depending on acid purity.



**FIGURE 4: Isocorrosion Chart for Type 316L Stainless Steel in Phosphoric Acid**

Material (°C)	Recommended Temperature Limit	Effect on Material
Carbon	100	None
Chlorinated Polyvinyl Chloride (CPVC)	20	None
Fiberglass Reinforced Vinylester (Hetron 942)	100	None
Fluorocarbons (TFE & FEP)	100	Slightly permeable at high temperatures
Polypropylene	20	None
Polyvinyl Chloride (PVC)	40	Some weight loss
Chlorobutyl Rubber	80	Some weight gain
Fluoroelastomer	80	Some weight gain

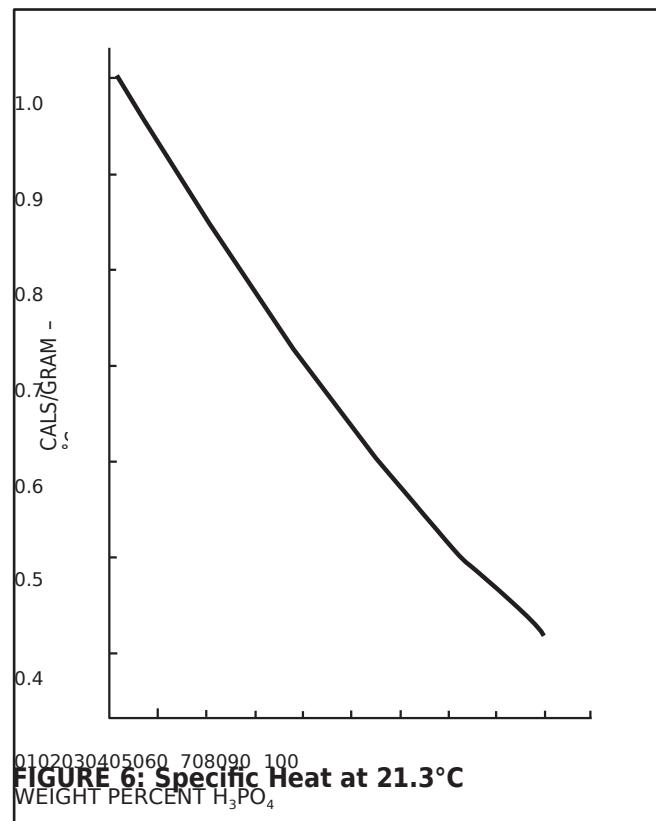
**FIGURE 5A: Corrosion Resistance of Non-Metals in 80% Phosphoric Acid**

Metal	Corrosion Rate (mils per year)				
	Temperature °C				Other
	25	50	75	100	
Mild Steel	>50	11,000	—	—	
Stainless Steel					
Type 304	—	—	—	50	Discolors
Type 316	—	—	—	2	
Type 347	—	—	—	0	
Type 430	—	—	—	3	Rate increases without aeration
Hastelloy B	<1	<1	1	5	
Hastelloy C	<1	<1	1	5	
Carpenter 20	—	—	—	2	
Nickel	0.3	4.2	—	150	
Monel	—	10	—	20	

**FIGURE 5B: Corrosion Resistance of Metals in 80% Phosphoric Acid**

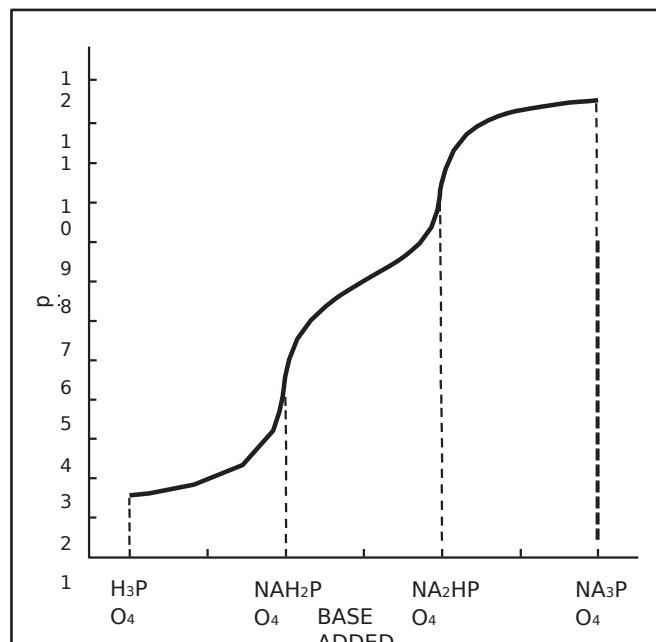
## Specific Heat

Figure 6 shows the weight percent of phosphoric acid in an aqueous solution versus the specific heat expressed as calories per gram — °C or (BTU/lb. — °F) at 21.3 °C.<sup>12</sup>



## Titration Curve

Figure 7 shows the curve for the titration of a 0.1 molar solution of phosphoric acid with sodium hydroxide. There are two distinct breaks in the titration curve which represent titration of the first hydrogen at about 4.2 pH and the second hydrogen at about 9.0 pH. Titration of the third hydrogen does not display a pH break but it is calculated to occur at about 11.5 pH.



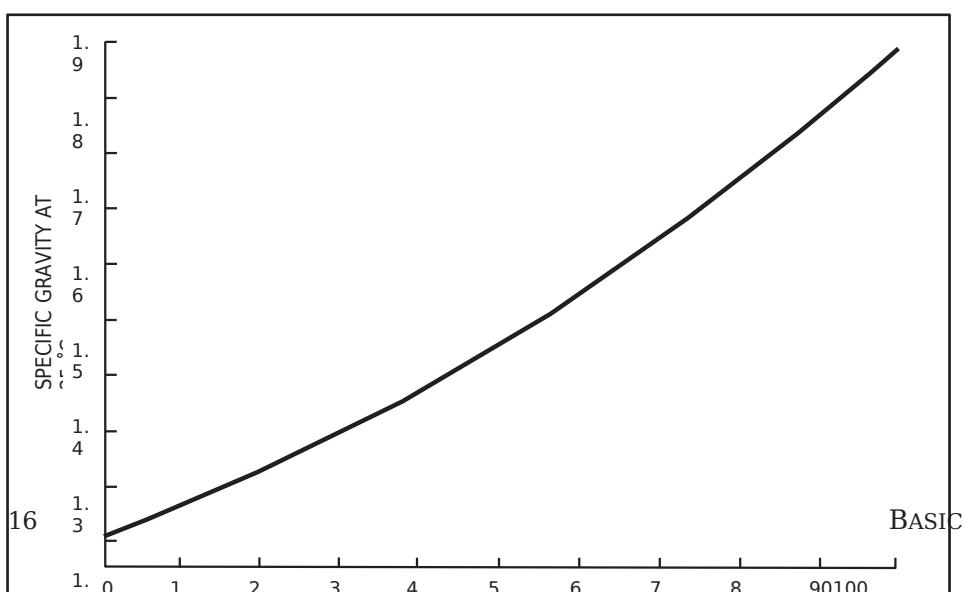
**FIGURE 7: Titration Curve of Orthophosphoric Acid pH versus Increasing Sodium Hydroxide Additions**

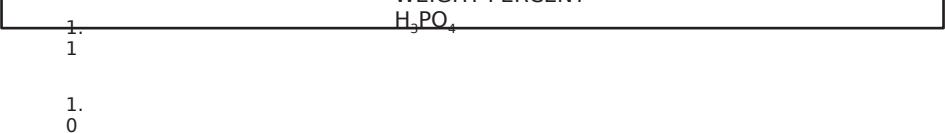
## Density

The density (expressed as specific gravity) versus concentration of orthophosphoric acid is given in the following chart<sup>(4)</sup> (Figure 8A) and graph (Figure 8B). Specific gravity is an accurate measure of the concentration of phosphoric acid for laboratory analysis. Linear interpolation between the values given in Figure 8A will yield acid concentrations with an accuracy of  $\pm 0.05\%$  H<sub>3</sub>PO<sub>4</sub> (see page 23 — Analytical Methods).

H <sub>3</sub> P O <sub>4</sub>	0	1	2	3	4	5	6	7	8	9
Wt. %										
0	.998	1.003	1.009	1.014	1.020	1.025	1.031	1.036	1.042	1.0480
	1 6	1	5	0	5	1	7	3		
10	1.05	1.059	1.065	1.071	1.077	1.083	1.089	1.095	1.101	1.1080
	38 5	4	3	3	3	4	5	6		
20	1.11	1.120	1.127	1.133	1.140	1.146	1.153	1.160	1.166	1.1738
	43 7	1	6	0	7	4	1	9		
30	1.18	1.187	1.194	1.201	1.209	1.216	1.223	1.231	1.238	1.2462
	07 7	8	9	2	4	8	2	7		
40	1.25	1.261	1.269	1.277	1.285	1.293	1.301	1.309	1.317	1.3263
	39 6	4	2	2	2	4	6	8		
50	1.33	1.343	1.351	1.360	1.369	1.378	1.387	1.396	1.405	1.4143
	47 2	8	5	2	1	0	0	1		
60	1.42	1.433	1.442	1.452	1.461	1.471	1.481	1.491	1.501	1.5114
	36 0	5	0	7	4	3	2	3		
70	1.52	1.532	1.542	1.552	1.563	1.574	1.584	1.595	1.606	1.6178
	16 0	4	9	5	2	9	8	7		
80	1.62	1.640	1.651	1.663	1.674	1.686	1.697	1.709	1.721	1.7334
	90 3	6	0	5	1	7	5	4		
90	1.74	1.757	1.768	1.781	1.793	1.806	1.818	1.831	1.843	1.8560
	55 8	8	3	7	2	6	1	6		
100	1.86	1.881	1.893	1.906	1.918	1.930	1.943	1.955	1.968	1.9808
	86 0	5	0	4	9	3	8	4		
110	1.99									
	33									

FIGURE 8A: Orthophosphoric Acid Specific Gravity @ 25°C/15.5°C versus Concentration





**FIGURE 8B: Specific Gravity versus Concentration**

## Dissociation

Orthophosphoric acid is a triprotic acid which means that it can contribute or dissociate three hydrogen ions. Dissociation of the first hydrogen is very strong and is exothermic. Dissociation of the second and third is weak and very weak, respectively, and both dissociations are endothermic. There is abundant research on the dissociation constants for the three hydrogens. R.G. Bates B<sup>(5)</sup> developed the following:

Hydrogen	Equation	Constant at 25°C
First H <sub>+</sub>	$-\log K_1 = 799.31/T^* - 4.5535 + 0.013486T$	$0.7107 \times 10^{-2}$
Second H <sub>+</sub>	$-\log K_2 = 2073.0/T - 5.9884 + 0.020912T$	$7.99 \times 10^{-8}$
Third H <sub>+</sub>	—	$4.8 \times 10^{-13}$

\* T is absolute temperature in degrees Kelvin

## Electrical Conductivity

The specific electrical conductivity of phosphoric acid increases with increasing concentrations reaching a maximum value at about 50% H<sub>3</sub>PO<sub>4</sub>. As the concentration continues to increase, the conductivity decreases. The electrical conductivity of any concentration increases with increasing temperature.

## Enthalpy – Concentration

Figure 9<sup>(8)</sup> (right), is a graph of the enthalpy versus concentration for phosphoric acid. This graph shows the heat evolved in calories per mole H<sub>3</sub>PO<sub>4</sub> when a certain concentration of acid is diluted to an infinitely low concentration. The heat evolved when acid of one concentration (C<sub>1</sub>) is diluted to a second concentration (C<sub>2</sub>) is found by subtracting the enthalpy of the second from the enthalpy of the initial solution (E<sub>C<sub>1</sub></sub> – E<sub>C<sub>2</sub></sub>).

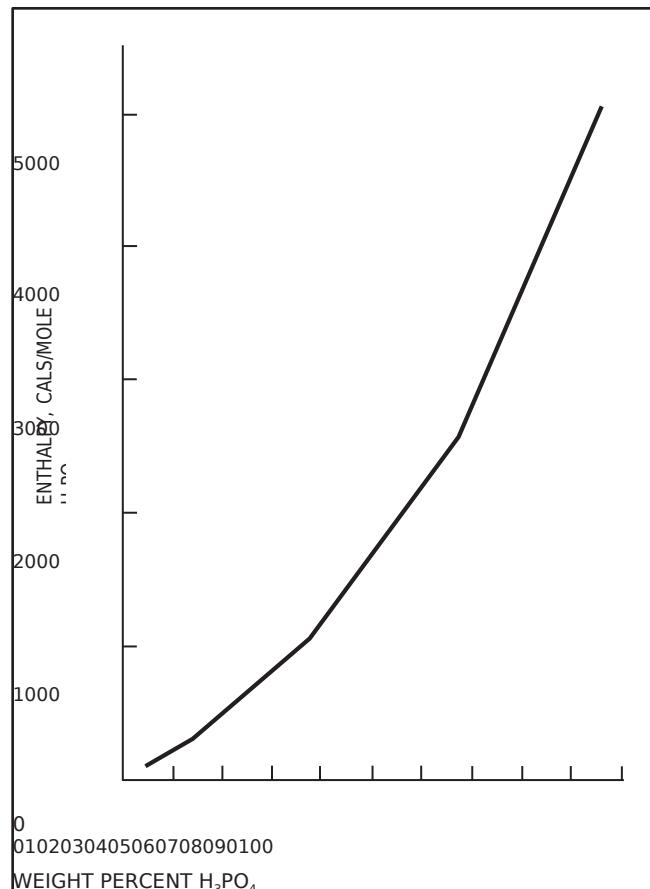


FIGURE 9: Enthalpy versus Concentration

## Heat of Formation, Free Energy of Formation, Entropy

The following is the heat of formation, free energy of formation and entropy of orthophosphoric acid as a solid and as an aqueous solution of 400 moles of water to 1 mole of  $\text{H}_3\text{PO}_4$ .<sup>(9)</sup>

	<b>Heat</b>	<b>Free Energy</b>	<b>Entropy</b>
	(kcal/mole) $\text{H}_{18}^{\circ}\text{C}$	(kcal/mole) $\text{F}_{25}^{\circ}\text{F}$	(cal/ $^{\circ}\text{C}$ ) $S$
100 wt. % $\text{H}_3\text{PO}_4$ (solid)	303.37	—	—
100 wt. % $\text{H}_3\text{PO}_4$ (liquid)	300.74		
Aqueous Dilutions			
84.5 wt. % $\text{H}_3\text{PO}_4$	302.49		
64.5 wt. % $\text{H}_3\text{PO}_4$	304.04		
37.7 wt. % $\text{H}_3\text{PO}_4$	305.26		
21.4 wt. % $\text{H}_3\text{PO}_4$	305.69		
9.8 wt. % $\text{H}_3\text{PO}_4$	305.93		
1.3 wt. % $\text{H}_3\text{PO}_4$	306.17	-270.0	42.1

## Latent Heat of Vaporization<sup>(8)</sup>

The latent heat of vaporization for phosphoric acid at 25 °C is given in Figure 10.

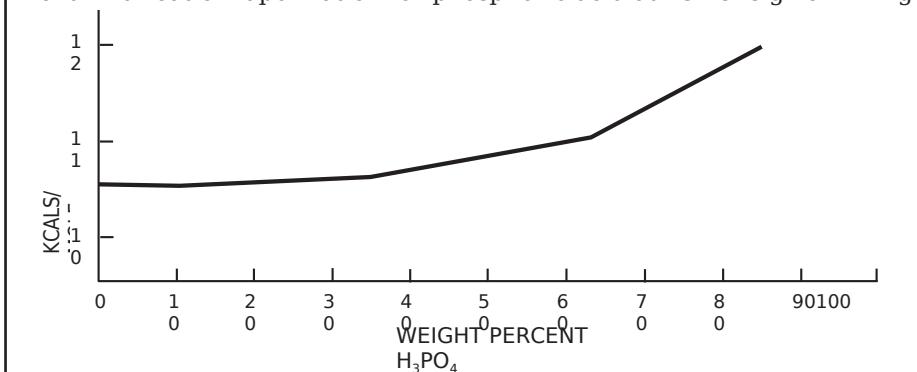


FIGURE 10: Latent Heat of Vaporization at 25°C

## Refractive Index

The refractive index of aqueous phosphoric acid solution is linear with concentration. The formula (17.5 °C)<sup>(10)</sup> is:

$$\text{Refractive Index} = 0.000792 \times (\text{weight \% } \text{H}_3\text{PO}_4) +$$

$$1.3346 \text{ or wt. \% } \text{H}_3\text{PO}_4 = \frac{\text{RI } 17.5^{\circ}\text{C} - 1.3346}{0.000792}$$

## Relative Sourness

Phosphoric acid is frequently used as a flavoring agent. It imparts a sour taste similar to citric, tartaric and acetic acid, however, the same level of sourness can be obtained using less phosphoric acid. The following table lists several acids, the relative sourness of a 0.01 N solution of each and the pounds of the listed acid equivalent to one pound of 75% phosphoric acid:<sup>(11)</sup>

	<b>Relative Sourness (0.01 N)</b>	<b>Equivalent Pounds of Acid</b>
Tartaric acid crystals (99.5%)	100	1.39
Citric acid crystals (91%)	100	1.29
Citric acid solution (50%)	100	2.35
Acetic acid (56%)	70	2.81
Lactic acid (44%)	100	3.76
Lactic acid (40%)	100	4.13
Phosphoric acid (75%)	120	1.00

Bottled soda of the acid type has a sourness approximately the same as 0.01 N solutions of citric, tartaric, or lactic acids.

## Vapor Pressure

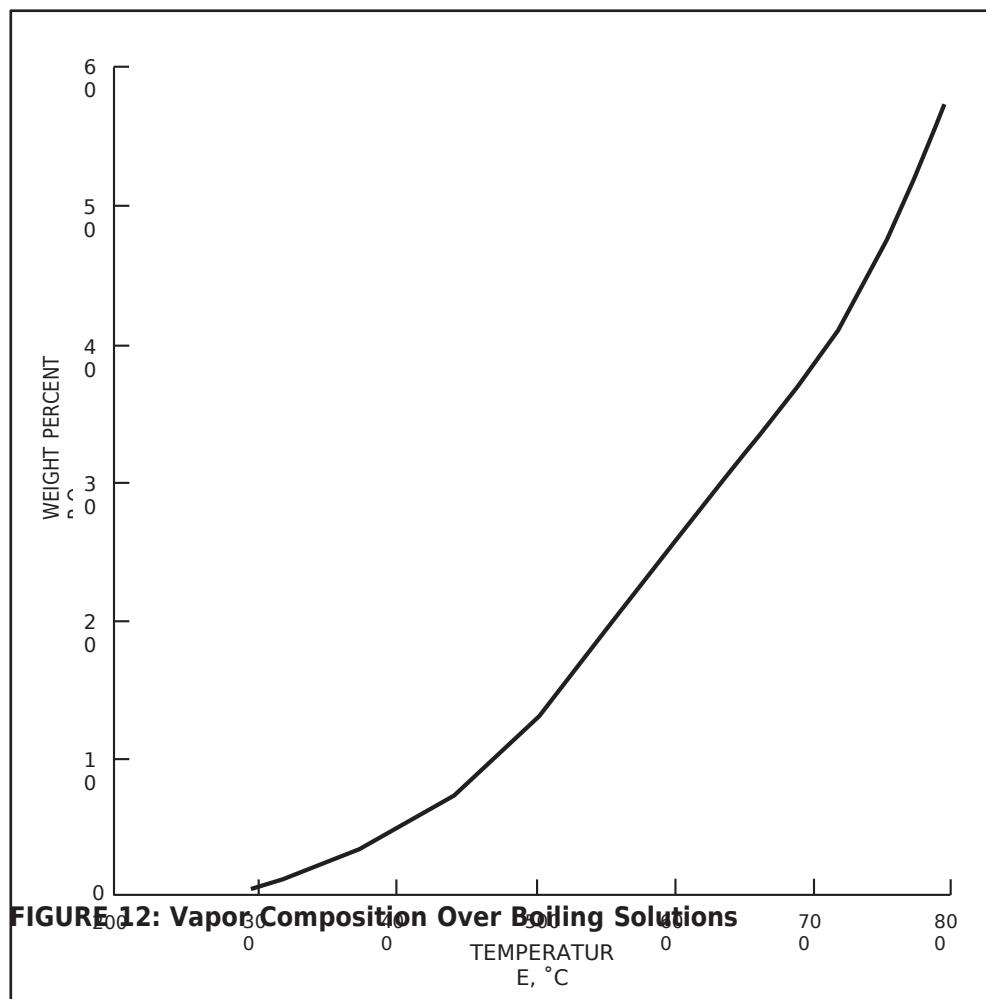
Figure 11 below gives the vapor pressure of water over aqueous solutions of phosphoric acid at various temperatures.<sup>(13)</sup>

Concentration (wt. % H <sub>3</sub> PO <sub>4</sub> )	Vapor pressure (mm Hg) at temperature (°C)				
	25°	40°	60°	80°	100°
0	23. 76	55.32	149.4	355.1	760.0
5	23. 47	54.6	148.0	349.0	745.0
10	23. 16	54.0	145.0	345.0	736.0
20	22. 40	52.2	141.0	335.0	713.0
30	21. 27	49.6	135.0	320.0	683.0
50	16. 68	39.4	108.0	262.0	567.0
65	10. 66	25.4	71.5	176.0	388.0
85	2.2 4	5.7	15.5	46.5	108.0
100	0.0 44	0.12	0.43	1.33	3.65

**FIGURE 11: Vapor Pressure versus Concentration**

## Vapor Composition

The composition of the vapor which exists over a boiling solution of phosphoric acid is depicted in Figure 12.<sup>(13)</sup> An aqueous solution of  $H_3PO_4$  will give off almost pure water for temperatures up to about 300 °C at which point the acid strength is about 103%. As the temperature of the solution increases, the vapor evolved will contain increasing amounts of  $P_2O_5$ . For example, the approximate composition of the vapor at 760 mm pressure over a boiling solution at 600 °C is 25%  $P_2O_5$ .

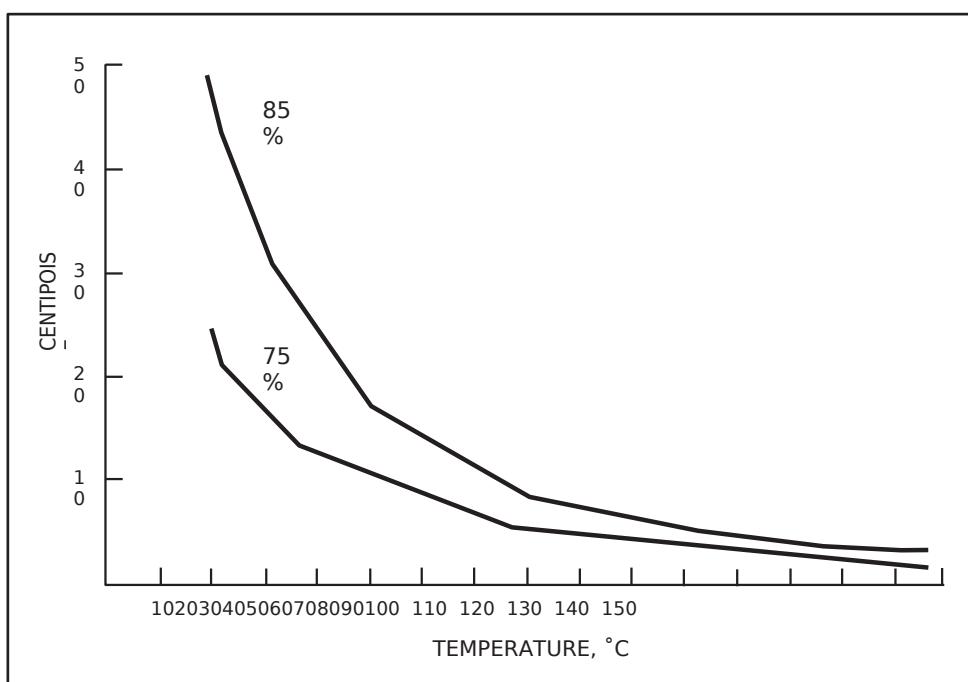


## Viscosity in Centipoise

Figure 13A below gives approximate viscosity in centipoises of aqueous phosphoric acid solutions for various concentrations and temperatures.<sup>(14)</sup> Figure 13B is a graph of the viscosity versus temperature for 75% and 85% phosphoric acid.

Concentration (%H <sub>3</sub> PO <sub>4</sub> )	Temperature (°C)							
	20°	30°	40°	60°	80°	100°	140°	180°
0	1.0	0.80	0.66	0.47	0.36	0.28	0.19	0.14
5	1.1	0.91	0.75	0.55	0.42	0.33	0.22	0.15
10	1.3	1.0	0.87	0.63	0.48	0.38	0.26	0.18
20	1.8	1.4	1.2	0.86	0.65	0.52	0.34	0.24
30	2.6	2.0	1.6	1.2	0.91	0.72	0.49	0.37
50	5.7	4.4	3.4	2.4	1.8	1.4	1.0	0.82
75	24.	16.	12.	7.4	5.1	3.8	2.4	1.8
85	47.	32.	23.	13.	8.4	5.8	3.5	2.4
105		644.	365.	145.	67.	35.	18.	
110		4510.	2240.	600.	250.	110.	40.	
115		16900.	10800.	2900.	975.	490.	155.	

**FIGURE 13A: Viscosity in Centipoise of Phosphoric Acid for Various Concentrations and Temperatures**



**FIGURE 13B: Viscosity of 75% and 85% Phosphoric Acid versus Temperature**

## Kinematic Viscosity of Phosphoric Acid Solutions

Figure 14 gives approximate viscosity in centistokes of aqueous phosphoric acid solutions for a full range of concentrations and temperatures.

%	Temperature, (°C.)																	
	20°	25°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	140°	150°	160°	170°	180°
H <sub>3</sub> P O <sub>4</sub>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1.90	0.90	0.86	0.65	0.56	0.48	0.42	0.37	0.33	0.30								
5	1.99	0.99	0.87	0.76	0.63	0.54	0.47	0.42	0.37	0.33								
10	1.11	0.91	0.89	0.88	0.71	0.61	0.54	0.47	0.42	0.38								
15	1.22	1.12	1.10	0.99	0.81	0.69	0.61	0.53	0.47	0.43								
20	1.44	1.31	1.30	1.11	0.92	0.78	0.69	0.60	0.54	0.48								
25	1.66	1.56	1.52	1.40	1.08	0.89	0.79	0.69	0.61	0.55								
30	1.92	1.79	1.74	1.42	1.00	0.90	0.79	0.70	0.62									
35	2.26	2.02	2.01	1.66	1.33	1.11	1.00	0.90	0.79	0.71								
40	2.60	2.36	2.31	1.99	1.55	1.33	1.22	1.00	0.90	0.81								
45	3.16	2.71	2.72	2.28	1.85	1.53	1.33	1.22	1.00	0.92								
50	3.73	3.37	3.32	2.66	2.11	1.88	1.66	1.44	1.22	1.11								
55	4.53	4.02	3.32	2.52	2.01	1.99	1.66	1.44	1.22	1.11								
60	5.66	5.09	3.91	3.15	2.52	2.22	1.99	1.77	1.44	1.33								
65	6.84	6.28	4.91	3.88	3.11	2.66	2.33	2.00	1.77	1.55	1.4	1.3	1.2	1.1	1.0	0.9	0.8	0.7
70	7.12	6.81	7.86	6.17	4.79	3.22	2.77	2.40	2.00	1.88	1.66	1.44	1.22	1.00	0.88	0.77	0.66	0.55
75	7.55	12.88	10.89	7.89	5.88	4.89	3.93	3.28	2.48	2.14	1.91	1.69	1.47	1.25	1.03	0.81	0.69	0.57
80	8.00	17.00	14.00	1.00	7.00	6.00	4.90	4.00	3.00	2.00	1.66	1.33	1.00	0.67	0.33	0.00	0.00	0.00
85	8.88	23.4	19.4	1.10	10.8	8.6	5.5	4.4	3.3	2.3	1.28	0.88	0.55	0.22	0.00	0.00	0.00	0.00
90	9.11	34.9	27.4	1.19	1.4	1.11	0.83	0.66	0.5	0.4	0.28	0.14	0.08	0.04	0.00	0.00	0.00	0.00
95	9.88	55.8	42.0	3.0	20.0	15.0	12.0	8.7	7.3	6.2	5.5	4.4	3.3	2.2	1.1	0.3	0.0	0.0
100	1.00	10.0	81.5	5.36	25.0	19.0	14.0	1.0	9.0	7.0	6.0	5.0	4.0	3.0	3.0	2.0	2.0	2.1

	4	0	3			1	2	7	2	2	5	1	5	2	
105	6	44	33	1	11	70	50	33	25	19	15	12	9.	8.	4.5
	0	0	0	7	0								6	0	1
				3									7.	6.	5.
110		22	16	8	41	27	17	10	67	50	38	29	22	18	15
		00	00	1	0	0	0	0					15	13	10
				0									8.8		
115					15	10	60	38	25	19	12	99	68	54	41
					00	00	0	0	0	0	0			34	28
118						20	12	83	55	40	32	21	17	13	10
						00	00	0	0	0	0	0	0	7	87

Bichowsky & Rossini: "The Thermochemistry of the Chemical Substances." Reinhold Publishing Corp.

**FIGURE 14: Viscosity in Centistokes of Phosphoric Acid for Various Concentrations and Temperatures**

# ANALYTICAL METHODS

## Determination of H<sub>3</sub>PO<sub>4</sub> by Specific Gravity

### Method: ASTM E358

#### Principle

The specific gravity can be accurately related to the strength of orthophosphoric acid.

#### Apparatus

1. Hydrometer, streamline or torpedo design, precision grade for liquids heavier than water in ranges suitable to the acid strength of thermal orthophosphoric acid.
2. Thermometer.
3. Hydrometer cylinder, glass, with or without lip, diameter 30 to 40 mm, height 325 to 375 mm.

#### Procedures

1. **Adjust the temperature of the sample to be tested to 20 ° to 30 °C**, thoroughly mix the sample and rinse a clean hydrometer cylinder with the sample.
2. Add the sample, and place the cylinder in a vertical position in a location free of air currents.
3. Grasp the top of the stem of a clean dry hydrometer between thumb and forefinger and slowly lower it into the center of the cylinder containing the sample. By sense of feel, gently release it just before it comes to rest. The free fall should be no more than 6 mm. No portion of the hydrometer should touch the cylinder.
4. The reading should not be taken until the liquid is free of any air bubbles and the hydrometer is at rest. In taking the reading, the eye should be placed slightly below the plane of the surface of the liquid and then raised slowly until this surface, seen as an ellipse, becomes a straight line. The point at which this line cuts the hydrometer scale should be taken as the reading.

#### Calculation

1. Determine acid strength opposite the appropriate specific gravity at 25 °C/15.5 °C in Table 2 (page 24) using the appropriate temperature coefficient factor in Table 1. (sp gr at T) + (T - 25) (temperature coefficient factor) = sp gr at 25 °C/15.5 °C

If the temperature of the determination is higher than 25 °C, plus correction will result. If lower than 25 °C, a minus correction will result.

TABLE 1: Specific Gravity Temperature Coefficient

H <sub>3</sub> PO <sub>4</sub> Percent	Solution, Temperature, °C		
	15	25	40
75	0.00074	0.00075	0.00076
80	0.00076	0.00077	0.00078
85	0.00078	0.00078	0.00080

**TABLE 2: Phosphoric Acid Solutions**  
**Specific Gravity Table based on ASTM Method E 358**

H <sub>3</sub> PO <sub>4</sub> Perce nt	P <sub>2</sub> O <sub>5</sub> Perce nt	Sp. Gr. 25C /15.5C	H <sub>3</sub> PO <sub>4</sub> Perce nt	P <sub>2</sub> O <sub>5</sub> Perce nt	Sp. Gr. 25C /15.5C
74.00	53.59	1.564	80.71	58.46	1.637
74.50	53.96	1.569	80.80	58.52	1.639
74.60	54.03	1.570	80.89	58.59	1.640
74.71	54.11	1.571	81.00	58.66	1.642
74.80	54.18	1.572	81.12	58.75	1.643
74.90	54.25	1.573	81.21	58.82	1.644
75.01	54.33	1.574	81.30	58.88	1.645
75.10	54.39	1.575	81.39	58.95	1.646
75.20	54.46	1.576	81.52	59.04	1.647
75.31	54.54	1.578	81.61	59.11	1.648
75.40	54.61	1.579	81.70	59.17	1.649
75.51	54.69	1.580	81.78	59.23	1.651
75.60	54.76	1.581	81.92	59.33	1.652
75.70	54.83	1.582	82.00	59.39	1.653
75.81	54.91	1.583	82.09	59.46	1.654
75.90	54.97	1.584	82.18	59.52	1.655
76.00	55.05	1.585	82.31	59.62	1.656
76.10	55.11	1.586	82.40	59.68	1.657
76.19	55.18	1.587	82.49	59.74	1.658
76.33	55.28	1.589	82.58	59.81	1.660
76.42	55.35	1.590	82.71	59.90	1.661
76.51	55.42	1.591	82.79	59.97	1.662
76.60	55.48	1.592	82.88	60.03	1.663
76.70	55.55	1.593	83.01	60.12	1.664
76.79	55.62	1.594	83.10	60.19	1.665
76.93	55.71	1.595	83.19	60.25	1.667
77.02	55.78	1.596	83.32	60.34	1.668
77.11	55.85	1.597	83.40	60.41	1.669
77.20	55.91	1.598	83.49	60.47	1.670
77.29	55.98	1.599	83.62	60.56	1.671
77.43	56.08	1.601	83.71	60.63	1.672
77.48	56.11	1.601	83.80	60.69	1.673
77.61	56.21	1.603	83.88	60.75	1.675
77.70	56.28	1.604	84.01	60.85	1.676
77.79	56.34	1.605	84.10	60.91	1.677
77.89	56.41	1.606	84.20	60.98	1.678
78.02	56.51	1.607	84.29	61.05	1.679
78.11	56.58	1.608	84.39	61.12	1.680
78.20	56.64	1.609	84.50	61.20	1.681
78.30	56.71	1.610	84.60	61.27	1.683
78.39	56.77	1.611	84.70	61.35	1.684
78.48	56.84	1.612	84.81	61.42	1.685
78.61	56.94	1.614	84.91	61.50	1.686
78.70	57.00	1.615	84.99	61.56	1.687
78.79	57.07	1.616	85.10	61.63	1.688
78.93	57.17	1.617	85.20	61.71	1.690
78.99	57.21	1.618	85.30	61.78	1.691
79.10	57.29	1.619	85.39	61.84	1.692
79.19	57.36	1.620	85.49	61.92	1.693
79.30	57.43	1.621	85.59	61.99	1.694
79.39	57.50	1.622	85.70	62.07	1.695
79.50	57.58	1.623	85.80	62.14	1.697
79.60	57.66	1.625	85.90	62.22	1.698
79.69	57.72	1.626	86.00	62.29	1.704
79.80	57.80	1.627	86.50	62.65	1.710
79.91	57.88	1.628	87.00	63.01	1.716
80.00	57.94	1.629	87.51	63.38	1.722
80.09	58.01	1.630	88.01	63.74	1.728
80.20	58.08	1.631	88.51	64.11	1.734
80.30	58.16	1.632	89.01	64.47	1.740
80.39	58.23	1.633	89.51	64.83	1.746
80.50	58.30	1.635	90.01	65.19	
80.59	58.37	1.636			

# Determination of H<sub>3</sub>PO<sub>4</sub> by Molybdo vanadate Method

## Principle

In a dilute orthophosphate solution, ammonium molybdate reacts under acid conditions to form a heteropoly acid, molybdophosphoric acid. In the presence of vanadium, yellow vanadomolybdophosphoric acid is formed. The intensity of the yellow color is proportional to the phosphate concentration.

## Reagents

Molybdo vanadate Reagent:

1. Solution A — dissolve 40 g ammonium molybdate tetrahydrate in 400 ml hot water and cool to room temperature.
2. Solution B — dissolve 2 g ammonium metavanadate in 250 ml hot deionized water. Cool to room temperature and add 330 ml of concentrated (36%) hydrochloric acid. Cool to room temperature.
3. Stirring constantly, slowly add Solution A to Solution B. Dilute to 2 liters with deionized water. Standard Phosphate Solution — Dissolve 0.3835 g reagent grade KH<sub>2</sub>PO<sub>4</sub> (dried at 105 °C for 2 hours) in deionized water and dilute to 500 ml. This solution contains 0.4 mg P<sub>2</sub>O<sub>5</sub>/ml. Make up weekly.

## Special Apparatus

Visible Spectrophotometer.

## Analytical Procedure

1. Turn spectrophotometer on, set the wavelength to 420 nm, and allow to warm up for the recommended period.
2. Weigh approximately 0.1 g of sample into a 100 ml volumetric flask. Record the weight (W) to the nearest 0.1 mg. Dilute to the mark with deionized water.
3. Pipet a 5 ml aliquot of above solution into a 100 ml flask. Add 40 ml of deionized water and, from a pipet, 20.0 ml of molybdo vanadate reagent. Dilute to the mark with deionized water, mix well.
4. With each set of samples, a reagent blank and a phosphate standard must be run. They are prepared as follows:
  - a. Blank: Pipet 20 ml of molybdo vanadate reagent into a 100 ml volumetric flask and dilute to the mark with deionized water. Mix well.
  - b. Standard: Pipet 5 ml of 0.4 mg P<sub>2</sub>O<sub>5</sub>/ml standard phosphate solution into a 100 ml volumetric flask. Add 40 ml of deionized water, pipet 20 ml of molybdo vanadate reagent and dilute to the mark with deionized water. Mix well.
5. Allow all samples, including the reagent blank and phosphate standard, to stand for 10 minutes.
6. When the spectrophotometer has warmed up, adjust the zero to read infinite absorbance. Place the blank in the spectrophotometer and adjust the light control to read 0 on the absorbance scale or display.
7. Place standard in the spectrophotometer and read the absorbance (A<sub>STD</sub>).
8. Place the sample in the spectrophotometer and read the absorbance (A<sub>SPL</sub>). Calculate the % P<sub>2</sub>O<sub>5</sub> or the % H<sub>3</sub>PO<sub>4</sub> as shown in the calculation section.

## **Calculatio**

$$\text{n} = \frac{4 \cdot A_{\text{SPL}}}{\text{Weight \% P}_2\text{O}_5 \cdot A_{\text{STD}} (\text{Sample Wt.})}$$

$$\text{Weight \% H}_3\text{PO}_4 = \% \text{ P}_2\text{O}_5 \times 1.3807$$

NOTE 1.  $\text{HClO}_4$ , or  $\text{HNO}_3$  can be substituted for  $\text{HCl}$ . A final acid concentration of about 0.5 N is recommended. See Note 2 for  $\text{HClO}_4$  precautions.

NOTE 2. Concentrated perchloric acid is an extremely strong acid and an extremely strong oxidizer. Contact with natural rubber or any other organic materials may cause a violent explosion. It must be stored away from heat and other materials. Never let any sample containing perchloric acid evaporate to dryness.

## **Determination of $\text{H}_3\text{PO}_4$ by Thymolphthalein Titration**

### **Reagents**

1. Thymolphthalein Indicator: Dissolve 0.10 g of thymolphthalein in 100 ml of methyl alcohol.
2. Sodium Hydroxide, 1.0 N: Standardized Titration Reagent.

### **Procedure**

1. Accurately weigh 1 ml (1.6 to 1.8 g) of the sample into a beaker. Add 120 ml of distilled or deionized water. Stir.
2. Add 0.5 ml of thymolphthalein indicator solution.
3. Titrate with 1 N sodium hydroxide ( $\text{NaOH}$ ) to the first appearance of a blue color.

## **Calculati**

### **on**

$$\% \text{ H}_3\text{PO}_4 = \frac{\text{ml NaOH} \times 4.900}{\text{Sample Wt.}}$$

# ENDNOTES

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